Kept in the dark

By Peter Spinks June 17, 2013, 12:05 a.m.

At face value, it seems to be present virtually everywhere, yet scientists still have precious little idea of what dark matter is. Widely believed to occupy large swathes of the cosmos, the controversial material – which has gravity but emits no light – has left scientists in the dark.

But now research aboard the International Space Station has uncovered what could be the telltale signature of dark matter, perhaps lurking somewhere near the outskirts of our galaxy, the Milky Way.

The signature comes in the form of a shower of antimatter, something formerly the stuff of science fiction.

It works like this: each particle of matter has a corresponding particle of antimatter, or antiparticle. This means there are antiparticles for each of the multitude of electrons, protons and neutrons that make up normal matter.

Antiparticle partners of subatomic particles have the same mass and spin but opposite charge and other attributes. The exception is force-carrying particles such as photons of light, which are identical to their antiparticles.

If particles of antimatter meet their opposite numbers, all hell breaks loose as they annihilate each other in a puff of pure, unadulterated energy.

In the vastness of deep space, the chance of annihilation is reduced and so cosmic rays provide an opportunity to study antimatter at first hand. This is what the space station particle detector did when measuring a stream of negatively charged electrons and their positively charged antiparticles, called positrons. These bombard the Earth every day.

The detector found more antiparticles than expected, travelling at almost the speed of light, says ICRAR-Curtin University astrophysicist Roberto Soria.

This was a surprise. Antiparticles such as the positron, after all, do not survive for long.

"With such great energies, they lose speed going through intergalactic space or destroy themselves in a flash of light on encountering a corresponding antiparticle," Dr Soria says.

The abundance of positrons suggests they come from relatively nearby within the Milky Way. "But it is not known exactly where and how they were produced," he says.

There are two competing explanations. The first is that they originate from the decay of "dark matter particles", thought to be present in the Milky Way's outer reaches.

"Many astronomers suspect there is a lot of dark matter in almost every galaxy, because the force of gravity is stronger than it would be if these galaxies contained only the stars and gas we observe," Dr Soria says. "In other words, the galaxies are heavy but we don't know what invisible objects make them so heavy."

If dark matter comprised atomic particles, he explains, they would decay into smaller entities over time, and may eventually produce electrons and positrons. This is why some scientists believe the detected flow of cosmic particles may be the signature of dark matter.

The second explanation is that pairs of electrons and positrons can be produced near the surface of compact, dead stars called pulsars, the closest of which are a few hundred light years away. (A light year is the distance travelled by light in the course of one year, roughly 9.5 trillion kilometres.)

Pulsars spin very rapidly – often at hundreds of times per second, compared with once a day for the Earth – and have a magnetic field thousands of billions of times stronger than that on Earth. Because of this, pulsars can create and accelerate electron-positron pairs, ejecting them into space at almost light speed.

It is still unclear how much rotational energy can be transferred to charged particles, Dr Soria says. But the latest results suggest that if about 4 per cent of a pulsar's spin energy is imparted to electron-positron pairs, there are enough pulsars a few thousand light years or less away to explain the number of high-energy cosmic electrons and positrons recorded.

Teasing out the truth

Several studies have tried to distinguish between the two possible explanations, but thus far to no avail. "Some scientists prefer the first model, others the second," Dr Soria says. "The only way to resolve the issue will be to measure more precisely where the particle stream is coming from in space, and check whether pulsars are there or only dark matter."

In a recently published paper, US-based FermiLab researchers Ilias Cholis and Dan Hooper summarised the situation thus: "Currently, we cannot yet discriminate between dark matter and pulsars as the source of the observed positron excess. We are hopeful, however, that future data

from AMS [the particle detector known as the Alpha Magnetic Spectrometer] may change this situation."

The crucial thing, they add, is to measure whether the positrons are produced within 30,000 light years or within less than a few thousand light years of the Earth. In the latter case, the dark matter could be ruled out as the possible source and the positrons would have to come from nearby pulsars.

History

Antimatter has mystified scientists since its discovery in the 1930s, when existing theories of particle physics were revolutionised. After British physicist Paul Dirac proposed the extraordinary idea in 1931, few believed him.

Scientists were used to talking about opposites in the sense of plus and minus when they talked about numbers: electric charges, bank charges, and so on. Cue a whole new concept of physics: matter and antimatter.

Although the universe today contains relatively little antimatter, the laws of physics suggest that it began with matter and antimatter in equal quantities. The origin of today's matter-antimatter imbalance is unknown, and remains one of the greatest conundrums of modern physics.

That may be about to change, thanks to a satellite that goes by the acronym PAMELA, which stands for Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics.

Structure of matter

Antiparticles, which are detected in phenomena as diverse as radioactivity and cosmic rays, are used by particle physicists to probe the fundamental structure of matter in accelerators such as the 27-kilometre-long Large Hadron Collider, currently closed for a re-fit, on the French-Swiss border.

Once it re-starts work, the colossal collider will be important in helping particle physicists understand what happened to all the antimatter early in the universe's development.

This may boil down to what amounts to an intrinsic asymmetry in the kaon and anti-kaon particle interaction, some scientists suggest. (Since they were discovered in 1947, kaons have helped lay the way for the standard model of particle physics, which sets out the arrangements of subatomic particles and their various properties.)

The intrinsic asymmetry, or imbalance, benefits matter at the expense of antimatter. It's a weak effect that may have been important after the big bang, during which the universe, along with time and space, is believed to have been created.

Given that the collider creates the sorts of conditions that existed immediately after the big bang, it may be able to measure this asymmetry directly within the next few years. Many physicists believe this might solve the mystery once and for all.

Other worlds

Antimatter composed of antiparticles is theoretically as stable as ordinary matter, but could only exist separately from it. Although none has been discovered so far, it has been suggested that antimatter galaxies or clusters of galaxies might exist somewhere out there in darkest, deepest space.

Back on planet Earth, meanwhile, there are numerous potential applications. Among other things, antimatter offers the prospect of perhaps becoming the ultimate energy source.

This, experts say, would be 1000 times more efficient than nuclear energy, with one gram being enough to power Melbourne for more than a day. But it's very expensive to make at the moment, and entails a process that is tortuously slow.

In the dark

Astronomers talk about it all the time, yet the presence of dark matter has never been directly verified. In essence, it is a convenient ad-hoc term to reconcile the observed motion of galaxies with the accepted laws of Newtonian gravity, Dr Soria suggests."I would not be certain that dark matter exists," he admits.

Dark matter, he adds, is "the lazy option". The hard option, he says, would be to admit that the law of gravity is wrong at large scales and needs to be improved. "Most astronomers prefer to take the easy option, but then they have no clue what dark matter could be."

Many possible exotic particles could act as dark matter, Dr Soria reminds. "Some of these may decay into simpler particles and eventually into electron-positron pairs. If so, the positrons found by the detector could be the signature of dark matter in the Milky Way."

Under this scenario, the cosmic flow of electrons and positrons might originate from a region 30,000 light years or so around us. "Particle physicists are now trying to determine which particles could produce the observed decay rate and the positron energy," he says.

Links

Read the latest results in the journal *Physical Review Letters* at: http://adsabs.harvard.edu/abs/2013PhRvL.110n1102A

The Cholis and Hooper research paper is at: http://adsabs.harvard.edu/abs/2013arXiv1304.1840C

Read about the PAMELA satellite and its mission to explore cosmic rays at: pamela.physik.uni-siegen.de/pamela/index.html

Delve deeper into the nature of fundamental physics in Frank Close's book, *Nothing: A Very Short Introduction* (Oxford University Press). Details: http://global.oup.com/academic/product/nothing-a-very-short-introduction-9780199225866

Find out what else is happening in our spellbinding universe in the Australian curriculum textbook Oxford Big Ideas Science 10 (Oxford University Press, 2012)

Learn more about the pioneering work of the International Centre for Radio Astronomy Research (ICRAR) at: http://www.icrar.org/

See some images from Dr Roberto Soria's work at http://www.ams02.org/ams-and-iss/where/

For more on the intriguing physics of antimatter, go to: http://physics.info/antimatter/

VCAA links

VCE physics:

www.vcaa.vic.edu.au/Documents/vce/physics/PhysicsSD-2013.pdf

VCE astronomy – Detailed study 3.1 for units 1 and/or 2 physics – accessed at VCE physics website above, p21

F-10 physics (under sub-strand "physical sciences" in AusVELS): http://ausvels.vcaa.vic.edu.au/Science/Curriculum/F-10

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http://www.bordermail.com.au/story/1576608/kept-in-the-dark/?cs=24